Strength variation and deformational behavior in anisotropic granitic mylonites under high-temperature and -pressure conditions – An experimental study

Gui Liu, Yongsheng Zhou , Yaolin Shi, Sheqiang Miao, Changrong He

Presented by: Charl D du Toit
Date: November 26th, 2018
GEOL.5200: Structural Geology

Outline

1. Introduction
2. Experimental samples and methods
3. Mechanical data
4. Microstructures of deformed samples
   - Compression tests at 30º angle to foliation plane
   - Compression tests at 45º angle to foliation plane
   - Compression tests at 60º angle to foliation plane
5. Conclusion and essence of paper

Introduction

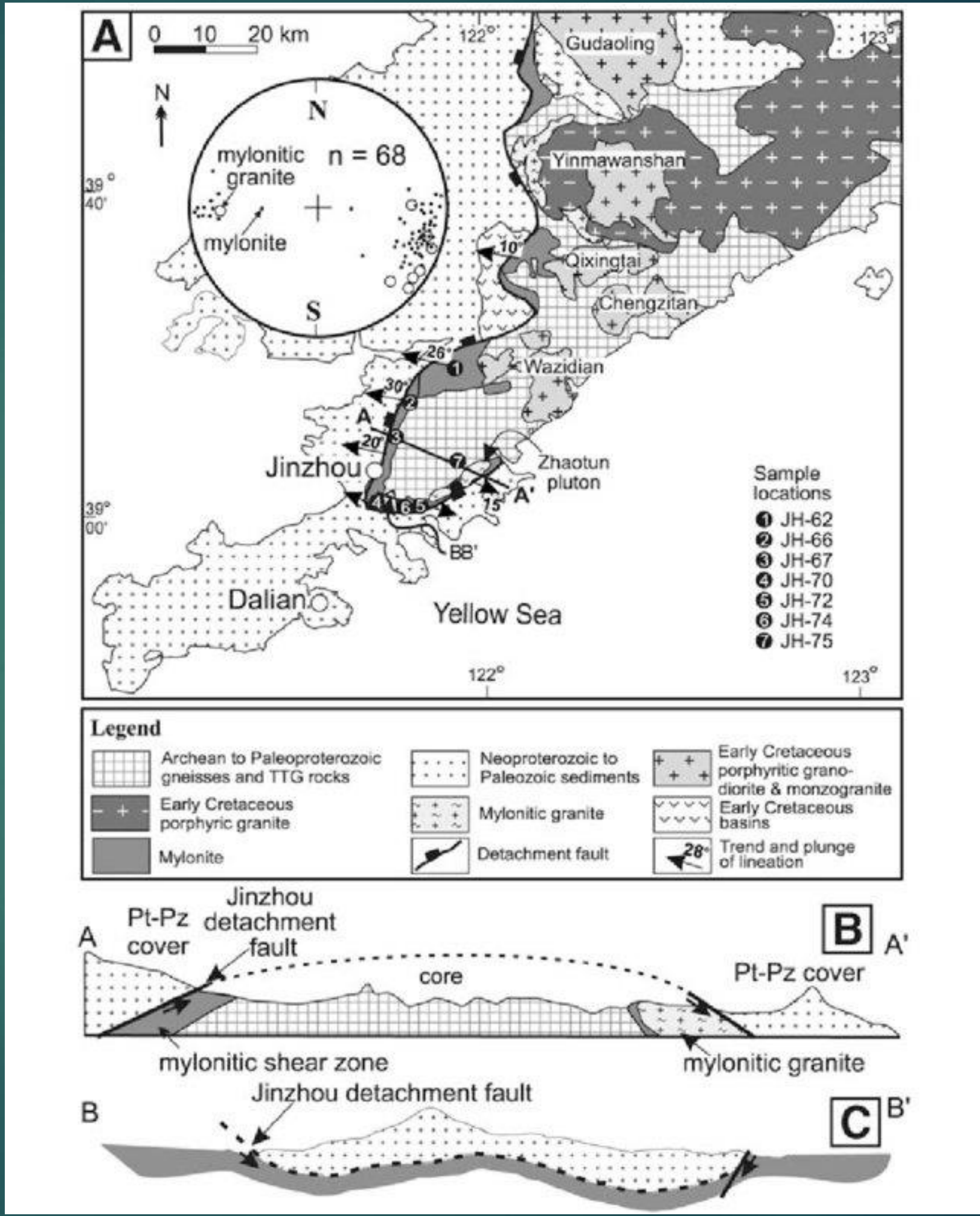
- Deformation experiments on foliated granitic mylonites under high P-T conditions were performed
- The effects of pre-existing fabric properties on the rheological behavior of the rocks were tested through different compression directions relative to the foliation planes at various P-T conditions and three incremental strain rate stages
  - Compression directions: 30º, 45º and 60º
  - Temperature range: 600 – 850 ºC
  - Confining Pressure range (Pc): 800 – 1200 Mpa
  - Strain rate range: 0.0001/s, 0.00001/s, 0.0000025/s

- Early studies on shear folding and failure demonstrated compressive strength is a function of angle between the foliation plane and the compression axis.
- Some findings on different rocks:
  - Mica-rich Schist samples with 45º axial load to foliation plane were often several times weaker vs. when loaded parallel (PAR) or perpendicular (PER) to foliation plane
  - Thin inter-layered Qtz-Fsp samples compressed normal to foliation planes were stronger vs. homogeneous isotropic mixtures under equivalent P-T conditions
- In experiments done on granitic mylonites samples where load was applied at 45º angle to foliation, the pre-existing fabric properties influenced the rheological properties of the rock significantly
- Strength of PER samples much higher vs. that of PAR samples under similar Temperature and strain rate ($\acute{\varepsilon}$)

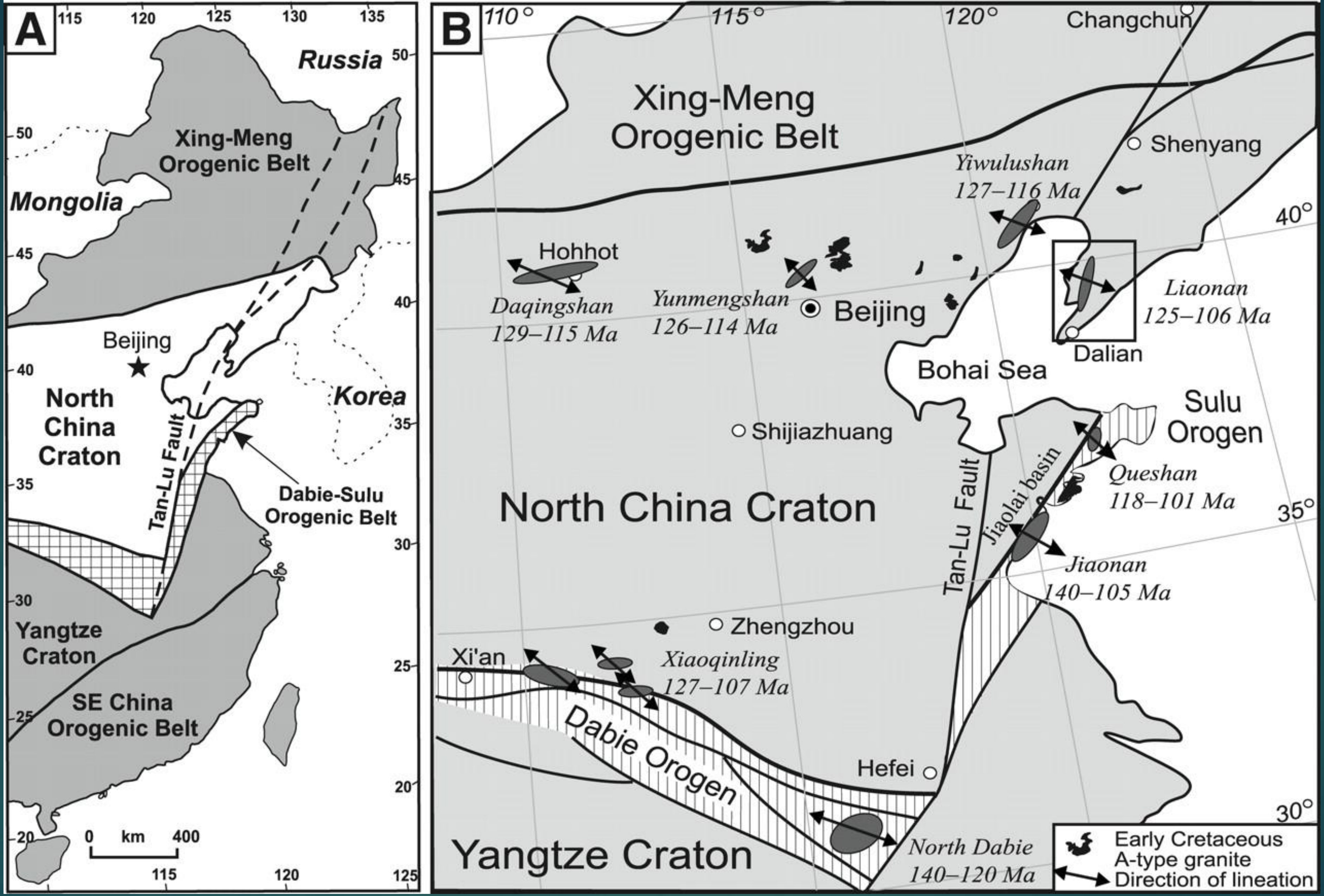
Pre-existing fabric properties of samples significantly influence the strengths of anisotropic samples

Experimental samples and methods

- Fresh, fine-grained granitic mylonite samples
- Collected from Jinzhou detachment fault, eastern Liaoning, on margin of North China craton



Simplified geologic map of Liaonan metamorphic core complex after (Yang et al., 2007)



Structural map of major geologic units in eastern China (Yang et al., 2007)

Experimental samples and methods

- Material was foliated with well developed lineation
- Microstructures were examined using polarizing optical microscope and SEM
  - Qtz grains displayed irregular undulatory extinction → implying sub-grain and dynamic recrystallization
  - Kinked and elongated Bt grains distributed along Qtz and Plag grains
  - Plag, K-fsp and Hbl grains less deformed
  - Bt, Qtz and Hbl form original foliation

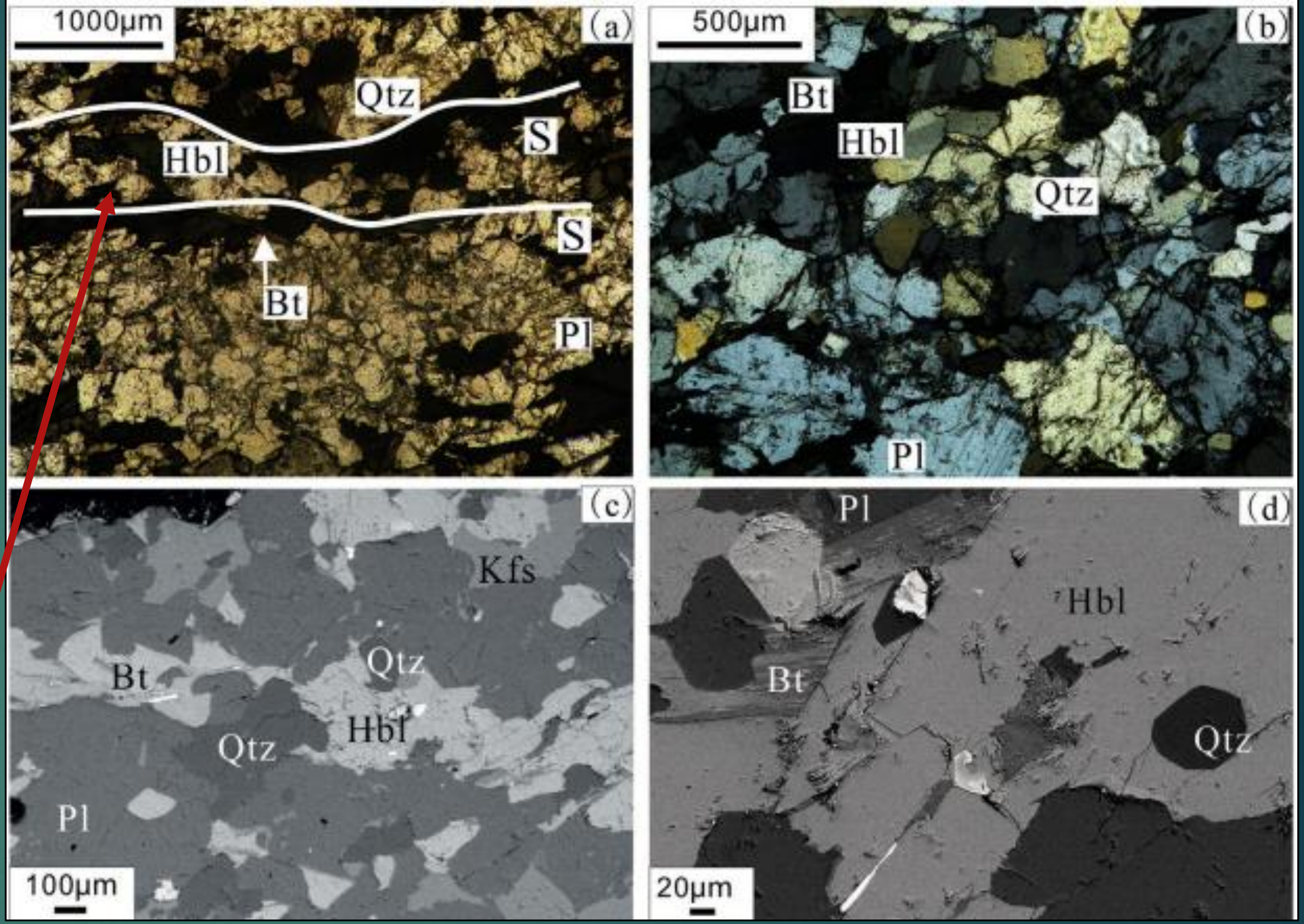


Figure 1: Microstructures of starting granitic mylonite sample. Modified after (Liu, Zhou, Shi, Miao & He, 2017).

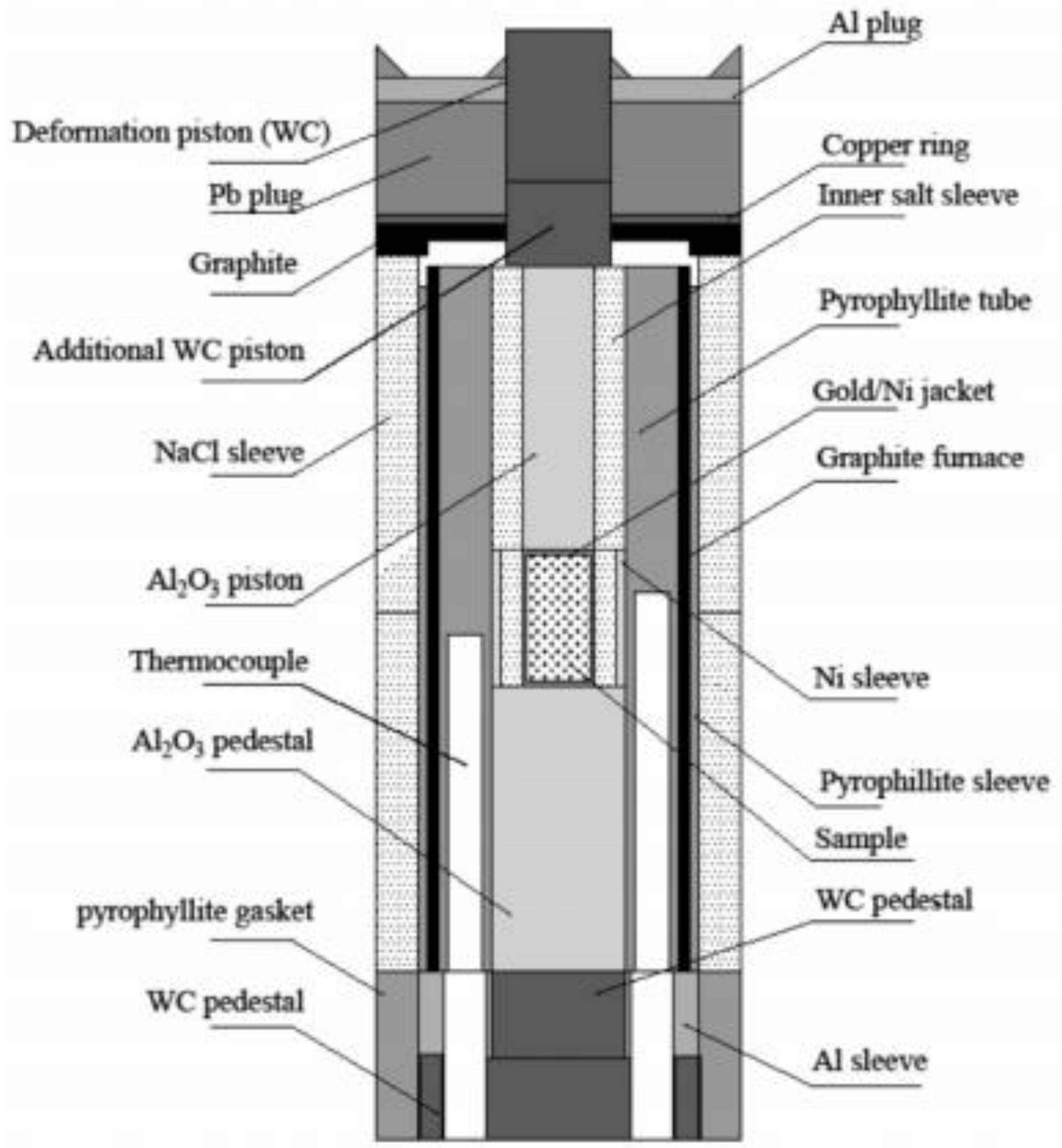


Fig. 2. Schematic of sample assembly of pressure vessel.

Figure 2: Schematic drawing of sample apparatus. Modified from (Liu, Zhou, Shi, Miao & He, 2017)

Experimental samples and methods

Experimental conditions:

- Temperature range: 600 – 850 ºC
- Confining Pressure range (Pc): 800 – 1200 Mpa
- Strain rate range: 0.0001/s, 0.00001/s, 0.0000025/s

- To allow for rheological strength comparison of material at different compression angles to original foliation plane, all experiments were conducted under same conditions (outlined above)
- When sample reached yielding point, strain rates were reduced to test strain rate dependence of material strength (step-wise reduction)

Mechanical Data

- Diff σ increase with increasing strain, especially at 1st step under $\dot{\varepsilon}$ = 0.0001/s
  - Strain hardening
  - No steady state flow reached
  - Deformation of samples is in semi-brittle regime

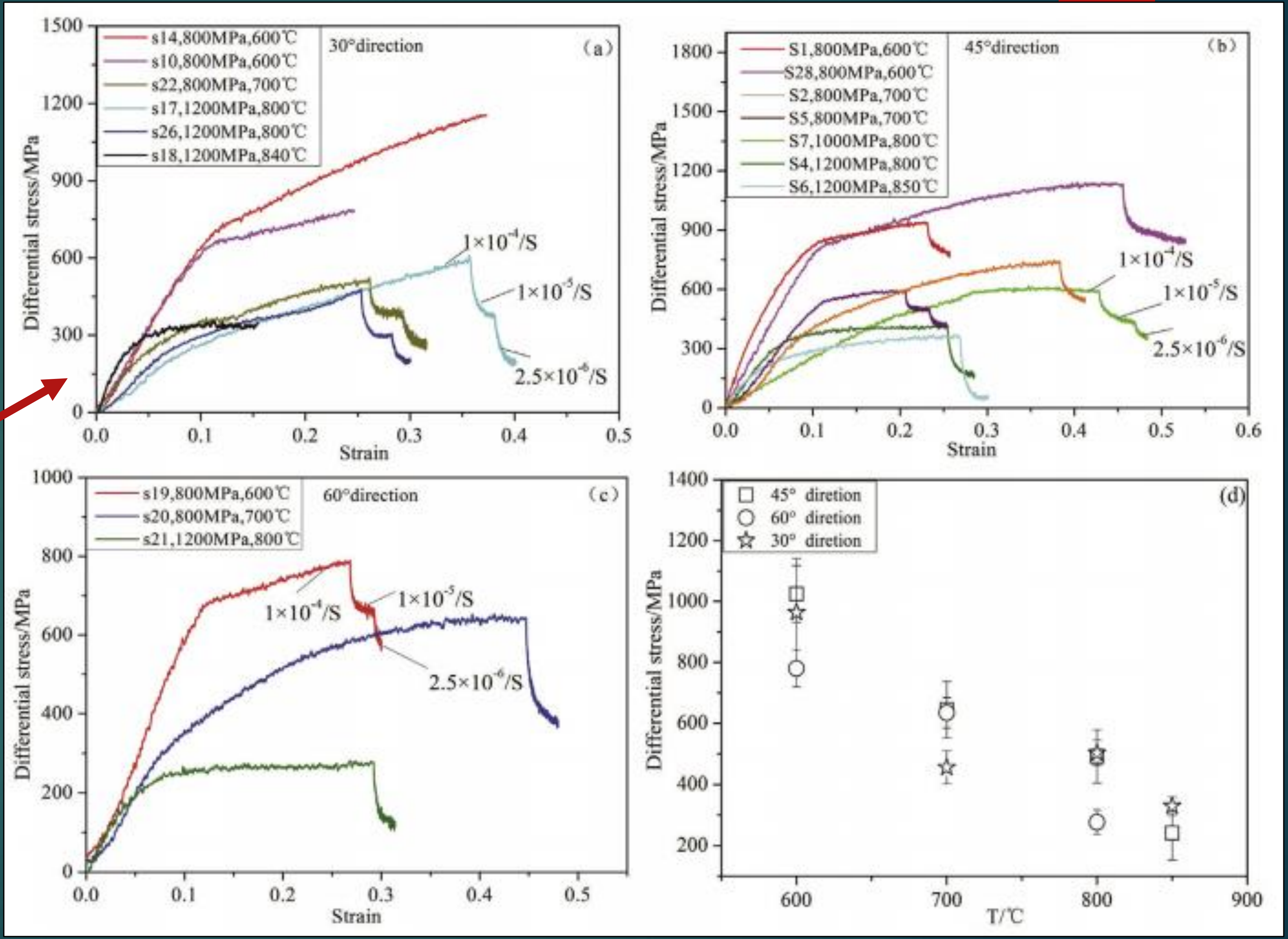


Figure 3: stress-stain curves of experimentally deformed granitic mylonite samples. Modified after (Liu, Zhou, Shi, Miao & He, 2017)

Mechanical Data

- Diff σ DECREASE with increasing strain, at 2nd and 3rd step under $\acute{\varepsilon}$ = 0.00001/s and 0.0000025/s
  - **Strain Softening** in deformed samples under LOWER $\acute{\varepsilon}$ and HIGH strain conditions

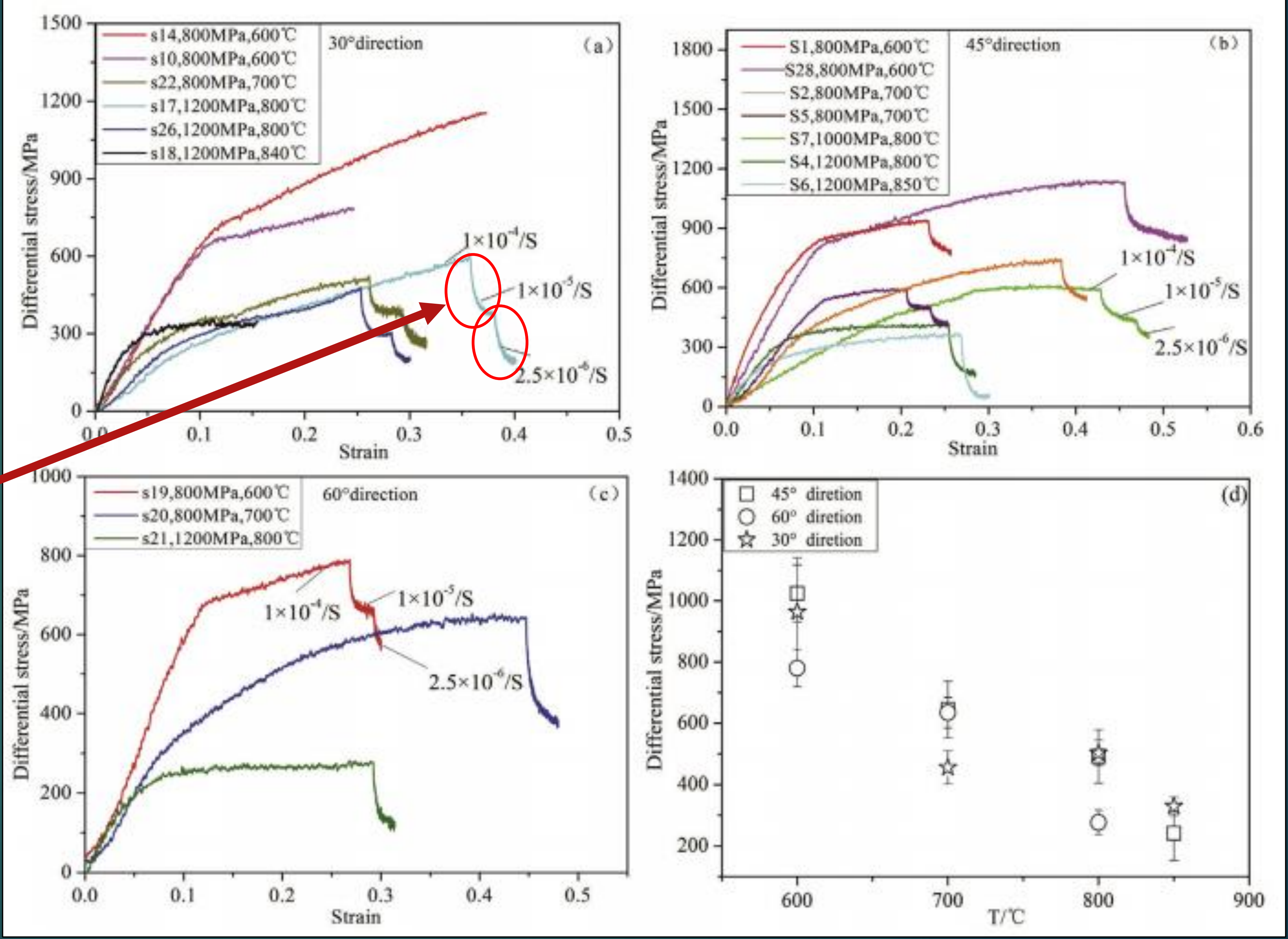


Figure 3: stress-stain curves of experimentally deformed granitic mylonite samples. Modified after (Liu, Zhou, Shi, Miao & He, 2017)

- Under constant Temperature and Pc, the mean strengths of samples decreased progressively as strain rate was reduced from 0.0001/s to 0.00001/s and again to 0.0000025/s
- At Pc of 800 to 1200 MPa, mean sample strengths DECREASED as Temperature increased from 600 to 850 ºC

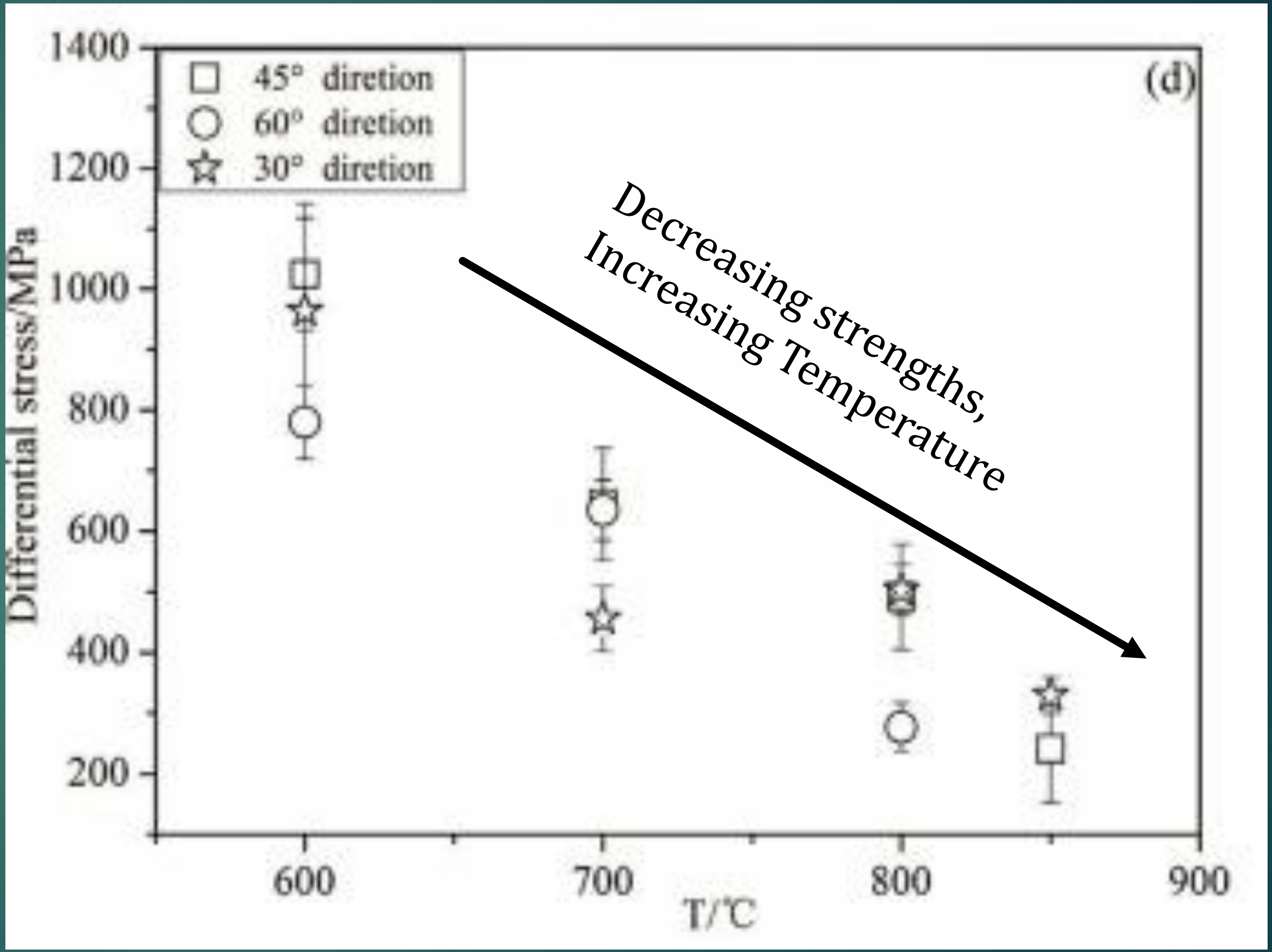


Figure 3d: the relationship between granitic mylonite sample strength with different fabric and temperature.

Compressed at 30º angle to foliation plane

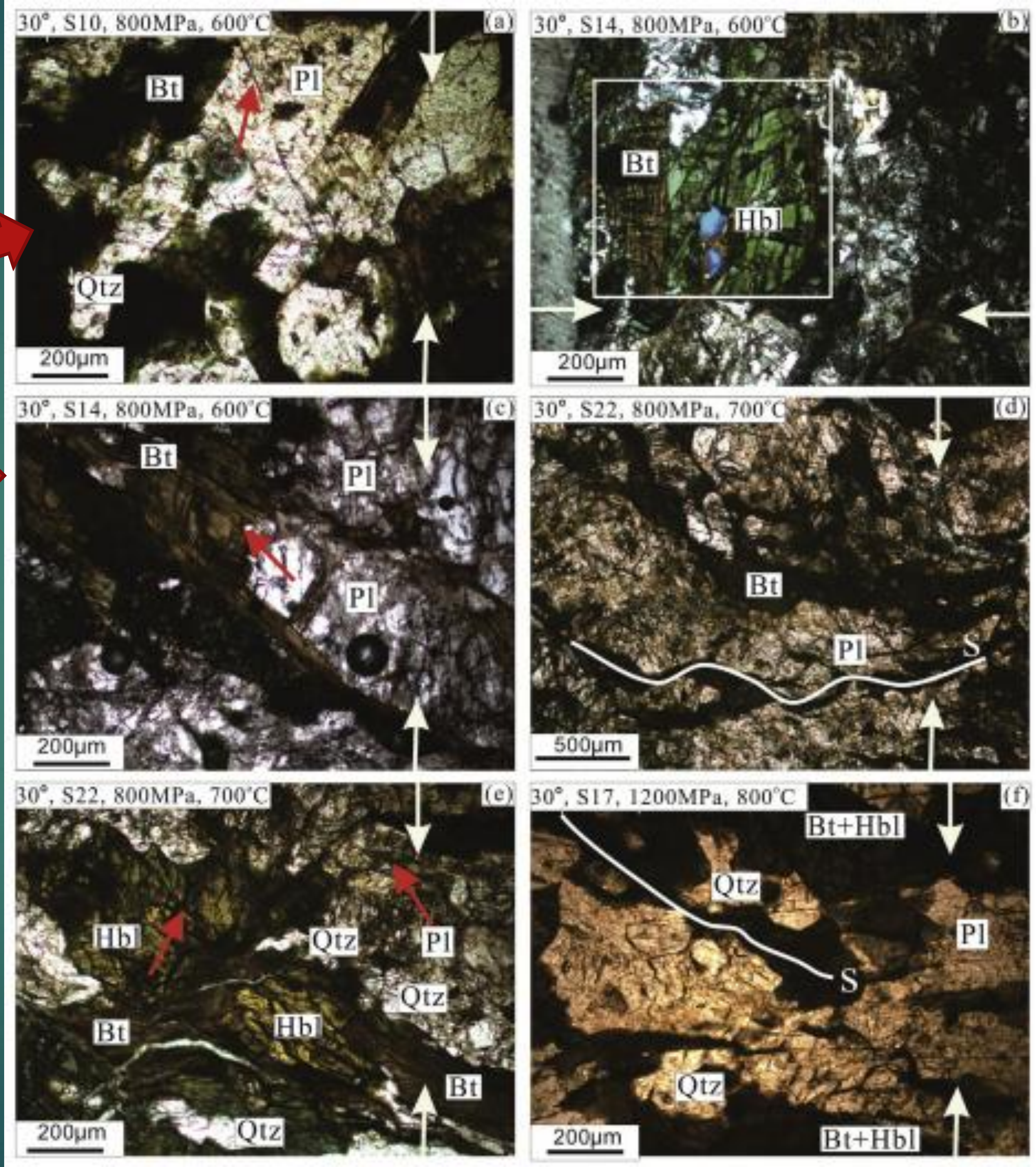
A-B: Plag. And Hbl. grains exhibit brittle deformation (brittle fracturing)

C: Bt. grains kinked at 600ºC

D: Original biotite bands transformed into new bands perpendicular (normal) to compression direction

E: Plag and Hbl grains broken at 700ºC

F: Elongation of Bt. And Hbl aggregates in shear bands



Compressed at 45º angle to foliation plane

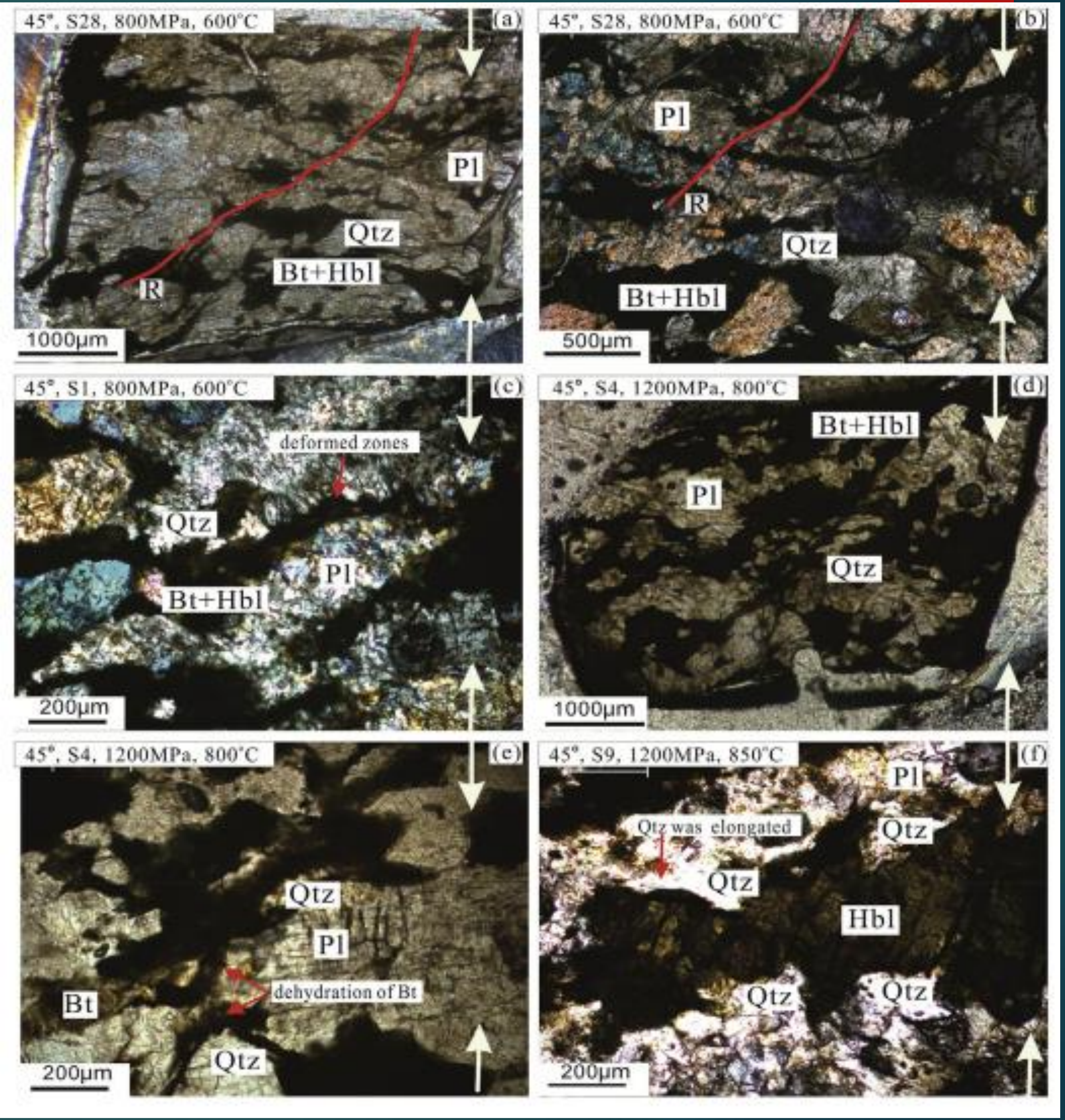
A-B: Brittle fractures at 45º to compression direction at 600ºC

C: Bt. Grains elongated as shear bands & Plag. Grains were broken.

D: INTER-granular fractures not as pronounced in Bt. And Hbl. Grains

E: Dehydration of Bt. Under 800ºC (Darkening under PPL)

F: Elongation of large Qtz. Grains, forming asymmetric tails



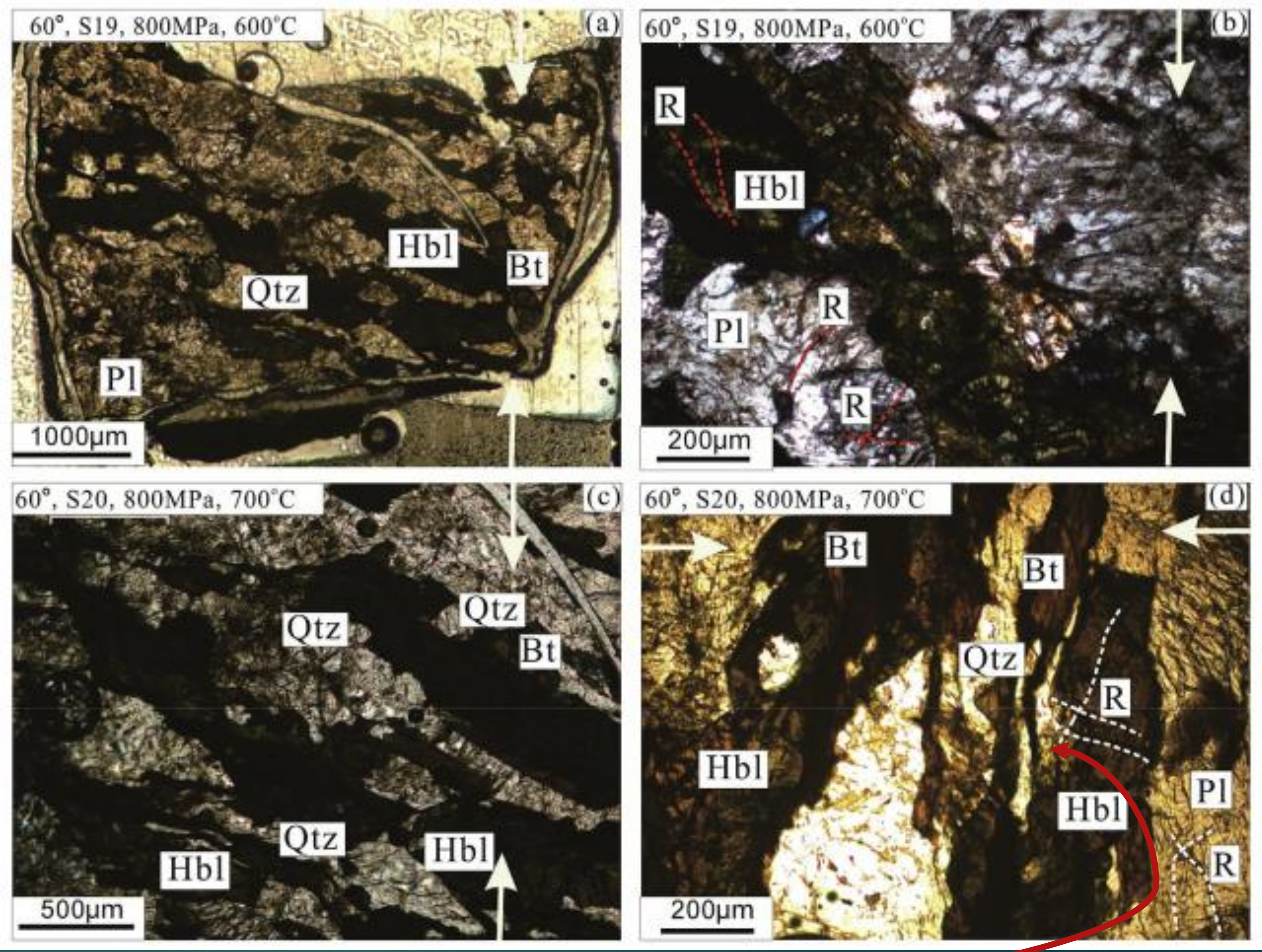
Compressed at 65º angle to foliation plane

A: Strongly deformed zones and fractures distribution controlled by Bt. And Hbl. Bands.

B: INTRA-granular fractures seen in most Plag. & Hbl. Grains.

C: Fine grained Qtz aggregates forming along Bt. And Hbl. Bands.

D: INTRA-granular fractures seen in most Plag. & Hbl. Grains.



Conclusion

1. Mechanical data:
   A. Strength of samples was lowest in semi-brittle deformation region (where compression applied at 30º angle to S-plane)
   B. Minimum strength reached in plastic deformation regime when applied load was at 45º angle to S-plane
   C. **Overall, compression applied at angles of 30-60º to S-plane revealed lower rock strengths than in cases where compression was applied normal (PER) and parallel (PAR) to S-plane.**
2. Experimental deformation generally intersected and replaced original foliation of the samples.
   A. **When angle oriented 30-45º**: New foliation formation during progressive deformation followed existing bands of Qtz and Bt.
   B. Whe**n angle oriented at 60º:** Experimental deformation replaced original foliation

Conclusion

3. All three sample groups exhibit semi-brittle fracturing at temperatures of 600-700ºC
4. Transition to plastic deformation at temperatures of 800-850ºC
5. Microstructure analysis after deformation revealed following:
   A. Aggregates of Bt. And Qtz. were strongly plastically deformed at Temperatures of 800-850ºC → becoming elongated and forming new foliation.
   B. At 800-850ºC: See micro-fracturing in Hbl. & Plag. + localized areas of plastic deformation.
   C. Dehydration along rims of Hbl. & Bt. grains → leading to recrystallization from partial melt (new crystals of Hbl and Bt develop)
   D. Dehydration melting mainly seen along original deformed bands and controlled by shear deformation
   E. New melt formation of mafic components dependent on adjacent minerals present.

References

- Liu, G., Zhou, Y., Shi, Y., Miao, S., & He, C. (2017). Strength variation and deformational behaviour in anisotropic granitic mylonites under high-temperature and-pressure conditions–An experimental study. *Journal of Structural Geology*, *96*, 21-34.
- Yang, J. H., Wu, F. Y., Chung, S. L., Lo, C. H., Wilde, S. A., & Davis, G. A. (2007). Rapid exhumation and cooling of the Liaonan metamorphic core complex: Inferences from 40Ar/39Ar thermochronology and implications for Late Mesozoic extension in the eastern North China Craton. *Geological Society of America Bulletin*, *119*(11-12), 1405-1414.